ISSN 1346-7565 Acta Phytotax. Geobot. 63 (1): 11–28 (2012)

Taxonomic Study of Podostemaceae in Loei Province, Northeastern Thailand

PETCHARAT WERUKAMKUL[1], LA-AW AMPORNPAN[2],
SATOSHI KOI[3] AND MASAHIRO KATO[4,*]

*[1]Faculty of Science and Technology, Rajamamgala University of Technology Phra Nakhon, 1381 Pibul Songkhram Road, Bangsue, Bangkok 10800, Thailand; [2]Department of Biology, Srinakharinwirot University, Sukumwit 23 Road, Bangkok 10110, Thailand; [3]Graduate School of Biological Sciences, Nara Institute of Science and Technology, Ikoma, Nara 630-0192, Japan; [4]Department of Botany, National Museum of Nature and Science, Tsukuba 305-0005, Japan. *sorang@kahaku.go.jp (author for correspondence)*

Previous floristic studies of Podostemaceae in Thailand recorded four species assigned to two genera in Loei Province, northeastern Thailand. Our explorations and taxonomic studies have resulted in six genera and 12 species from the Province, including four new species (*Terniopsis heterostaminata*, *T. filiformis*, *Hydrobryum phurueanum*, and *H. varium*), two new records to Thailand (*H. vientianense* and *Polypleurum pluricostatum*), two new records to Loei (*Dalzellia kailarsenii* and *Thawatchaia trilobata*), and new localities in Loei of the remaining four species. All species are strictly or moderately narrowly distributed, but *H. japonicum* is widely distributed. The species of *Terniopsis* differ from each other and from their congeners by the number of stamens, the length of the stamens relative to ovary, and the form of the stigmas. The new species of *Hydrobryum* are distinct in the caudate or acuminate long bract and in the long pedicel. *Hydrobryum* is the largest genus in Loei with six species. Four or five species occur densely in each of three rivers constituting a single river system in the Province. Loei is among the most species-rich areas in Thailand due to the mostly mountainous topography.

Key words: *Dalzellia*, *Hanseniella*, *Hydrobryum*, *Polypleurum*, *Terniopsis*, *Thawatchaia*

The aquatic flowering plant family Podostemaceae is distributed in tropical regions worldwide, but rare in temperate regions (Cook & Rutishauser 2007). The plants live in extreme habitats without strong plant competitors, except for Hydrostachyaceae in Africa and Madagascar. They grow only in open areas, attaching to water-worn rocks or hard substrata of riverbeds, rapids and waterfalls that are subject to seasonal changes in water level (Willis 1902, Sculthorpe 1967). The vegetative plant body is immersed in rapidly flowing water during the rainy season. As the water level recedes towards the close of the rainy season, flowers, which open when exposed to air, are formed. Fruits and seeds quickly develop while the plants dry.

Podostemaceae, known as "dok hin" in Thai (*dok*, flower; *hin*, rock or stone), are found across Thailand, particularly in mountainous areas with suitable rapids and waterfalls. The Podostemaceae of Thailand have been poorly known taxonomically, phylogenetically and morphologically. Kato and coworkers' comprehensive studies and extensive field surveys throughout Thailand have significantly increased our knowledge of the diversity of the family. The number of taxa in Thailand has been increased from seven genera and 10 species (Cusset & Cusset 1988, Cusset 1992) to 10 genera and 42 species with 4 varieties (Kato 2004, 2006a, Kato *et al.* 2004, Kato & Koi 2009).

Most of the 42 species are endemic to Thailand. *Cussetia*, *Dalzellia* and *Terniopsis* represent the subfamily Tristichoideae in Thailand, while the remaining seven genera, *Cladopus*, *Hanseniella*, *Hydrobryum*, *Paracladopus*, *Polypleurum*, *Thawatchaia* and *Zeylanidium*, represent subfamily Podostemoideae (Kato & Koi 2009). The largest genus is *Hydrobryum* with 12 species and two varieties, followed by *Polypleurum* with 11 species and two varieties (Kato & Koi 2009). Based on distributional and other data, Kato (2006b) pointed out that Thailand is likely a core region for the diversification of Podostemaceae in Asia.

Kato (2004) and Kato & Koi (2009) recorded four species of Podostemaceae from Loei Province, northeastern Thailand; *Hydrobryum japonicum* Imamura, *H. loeicum* M. Kato, *H. tardhuangense* M. Kato, and *Hanseniella heterophylla* C. Cusset. *Hydrobryum japonicum* is the most widely distributed among Asian species, ranging from northern Myanmar, Thailand and northern Vietnam to southwestern China and Japan (Cusset 1992, Kato 2004, Tanaka *et al.* 2006, Kato 2011). In contrast, the other two species are restricted to Thailand. *Hydrobryum tardhuangense* was recently recorded from north-central Laos (Koi & Kato 2012). *Hydrobryum tardhuangense* and *H. loeicum* occur in the Hueang River of Na Haeo District, Loei (Kato 2004). The former grows only in Tat Hueang waterfall in Phu Suan Sai National Park, while the latter occurs in several waterfalls or rapids in two rivers of the Hueang River system (Kato 2004, Kato & Koi 2009). *Hanseniella heterophylla* was recorded from the San River in Phu Ruea District, Loei, and in Tung Salaeng Luang National Park in adjacent Pitsanulok Province (Cusset 1992, Kato 2004). Based on recent additional collections, this paper describes a total of six genera and 12 species from Loei, indicating that the province is a markedly species-rich area in Thailand.

Materials and Methods

Loei Province, covering approximately 11,424 km^2, is situated at 16°45′–18°11′ N, 100°50′–102°05′ E on the Phetchabun Mountain Range and lies in the northernmost part of northeastern Thailand. About 80% of its area is overlapping and undulating mountain ranges. There are high mountains (400–1,570 m) in Dan Sai, Na Haeo, Phu Luang, Phu Ruea and Tha Li Districts in the western part of the Province. Hueang, Loei, Mon and San are major rivers, arising in the western mountain areas and flowing into the Kong River (Mekong). Within the largely mountainous terrain are many waterfalls and river rapids suitable for Podostemaceae.

Two of us (P.W. & L.A.) implemented extensive field surveys of the waterfalls and swift-flowing rivers with rock substrata in Hueang, Loei, since November 2009 (Fig. 1). The delineation of the species is based on comparative morphology and molecular phylogenetic analysis (Warming 1901, Cusset & Cusset 1988, Cusset 1992, Cook 1996, Kato 2004, 2006a, Cook & Rutishauser 2007, Kato & Koi 2009, Koi & Kato 2012). Specimens examined in this study are housed in Forest Herbarium (BKF), Department of National Parks, Wildlife and Plant Conservation, Bangkok, the Department of Biology, Srinakharinwirot University, Bangkok, Thailand, and in the herbarium (TNS) of the Department of Botany, National Museum of Nature and Science, Tsukuba, Japan.

The enumeration below cites specimens recently collected from Loei Province, but does not cite specimens examined in previous studies (Kato 2004, 2006a, Koi & Kato 2012). The ecology of the species is unexceptionally uniform, like that of all other podostemads, so it is not noted under each species. The plants are aquatic lithophytes preferring dual environments in a seasonal climate, i.e., submerged in the wet season and flowering and fruiting while emergent in the dry season.

Results and Discussion

Among the 12 species found in Loei Province, three species are assigned to two genera of subfamily Tristichoideae, and nine species to four genera of Podostemoideae. Most species are local while only *Hydrobryum japonicum* is widely dis-

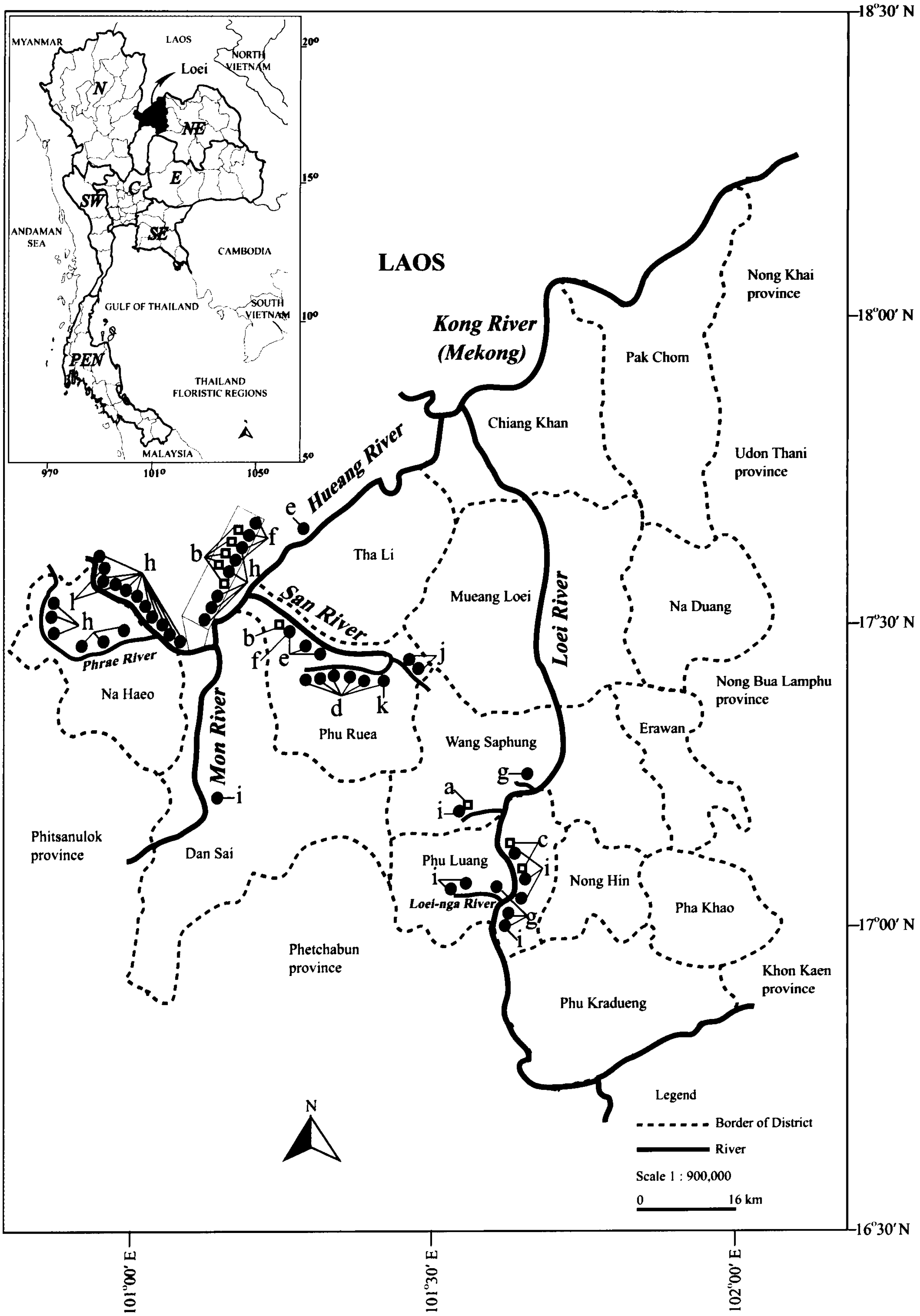

FIG. 1. Map of Loei Province showing distribution of Podostemaceae. Inset shows phytogeographic division of Thailand with Loei in northeastern Thailand. Open squares and solid circles indicate Tristichoideae and Podostemoideae; letters (a–l) indicate species. a, *Dalzellia kailarsenii*; b, *Terniopsis heterostaminata*; c, *Terniopsis filiformis*; d, *Polypleurum pluricostatum*; e, *Hanseniella heterophylla*; f, *Thawatchaia trilobata*; g, *Hydrobryum japonicum*; h, *Hydrobryum loeicum*; i, *Hydrobryum vientianense*; j, *Hydrobryum phurueanum*; k, *Hydrobryum varium*; l, *Hydrobryum tardhuangense*.

tributed in Southeast and East Asia (Fig 1). *Hydrobryum vientianense* has a relatively wide distribution in Loei, but is nonetheless restricted to the Loei and Mon rivers. *Hydrobryum varium*, restricted only to Huai Phai waterfall in Phu Ruea National Park, has the narrowest distribution. *Hydrobryum phurueanum* is found in two localities in a single stream in Phu Luang Wildlife Sanctuary, Phu Ruea District. The narrow distributions of most species agree with Cook & Rutishauser's (2007) remark that many Podostemaceae are endemic to narrow geographic areas or single countries.

Loei Province is a mountainous region with many waterfalls and rapids suitable for Podostemaceae. Our study shows it to be a biodiversity hotspot for Podostemaceae with 12 species, the largest number of species per province in Thailand. It is followed by Chiang Mai Province (8 species) in northern Thailand and Ubon Ratchathani Province (7 species) in eastern Thailand (Kato 2004, 2006a, Kato & Koi 2009). Using IUCN (2011) criteria, it is estimated that the species are threatened to different degrees; four species are Critically Endangered, three are Endangered, four are Near Threatened, and one is Least Concern.

Key to the species of Loei

1a. Leaves linear-lanceolate or elliptic, spaced, flat; flowers actinomorphic, spathella absent; tepals 3, connate, 3-lobed, membranous; stamens 2 or 3, alternate tepals (if 2, one is lacking); ovary 3-locular; capsule dehiscing by 3 valves (subfamily Tristichoideae) 2
1b. Leaves filiform, tufted, terete; flowers zygomorphic, spathella enclosing flower bud; tepals 2, filiform, on both sides of filament (andropod); stamens 1 or 2, if 2, united to common andropod; ovary 2-locular; capsule dehiscing by 2 valves (subfamily Podostemoideae) 4
2a. Root absent; shoots creeping on and adhering to rock, crustaceous, with leaves on dorsal and marginal surface .... 1. *Dalzellia kailarsenii*
2b. Roots creeping on and adhering to rock, narrowly ribbon-like; shoots short, leafy, on flanks of root, with leaves in 3 files 3
3a. Stamens 2, one appearing earlier than the other and apparently solitary, rarely 3, stigmas cristate .... 2. *Terniopsis heterostaminata*
3b. Stamens 3, rarely 2; stigmas cristate when young, forked, filiform at maturity .... 3. *Terniopsis filiformis*
4a. Root ribbon-like; tufts of leaves and flowering shoots borne at sinuses between root branches; flowers stalked, stamen 1 .... 4. *Polypleurum pluricostatum*
4b. Root crustaceous; tufts of leaves and flowering shoots scattered on dorsal surface of root; flowers subsessile, stamens 2 with common andropod 5
5a. Flowering shoots usually erect; bracts in 4 ranks, dimorphic, ventral bracts bilobed, dorsal bracts simple .... 5. *Hanseniella heterophylla*
5b. Flowering shoots appressed; bracts in 2 ranks, uniform 6
6a. Bracts trilobed; spathella mucronate at apex .... 6. *Thawatchaia trilobata*
6b. Bracts simple; spathella obtuse or truncate at apex 7
7a. Spathella smooth; ovules 14–16 per locule, on marginal surface of septum .... 7. *Hydrobryum japonicum*
7b. Spathella papillate; ovules 4–37 per locule, on central and marginal, or only on marginal surface of septum 8
8a. Apex of bract obtuse 9
8b. Apex of bract acuminate or caudate 10
9a. Spathella ruptured irregularly near apex; ovules 4–11 per locule, on marginal surface of septum; seeds 0.5–0.8 mm long .... 8. *Hydrobryum loeicum*
9b. Spathella ruptured longitudinally; ovules 8–23 per locule, on whole surface of septum except in lower central area or on marginal surface; seeds 0.3–0.5 mm long .... 9. *Hydrobryum vientianense*
10a. Bract to 13 mm long, apex long caudate; andropod of stamen as long as, or shorter than ovary .... 10. *Hydrobryum phurueanum*
10b. Bract to 4.5 mm long, apex acuminate; andropod of stamen much longer than ovary 11
11a. Pedicel 0.6–2 mm long; gynophore 0.5–1.6 mm long; ovules (11–)23–37 per locule, rarely fewer; stalk of capsule 1.5–3 mm long .... 11. *Hydrobryum varium*

11b. Pedicel 0.3–0.7 mm long; gynophore 0.4–0.6 mm long; ovules 11–19 per locule; stalk of capsule 0.7–1.3 mm long .... 12. *Hydrobryum tardhuangense*

1. **Dalzellia kailarsenii** M. Kato in Acta Phytotax. Geobot. 57(1): 12, f. 4, 2006.

Roots absent. Shoot crustose or broadly ribbon-like, attached over rock surface, 1.5–2.5 mm wide, dichotomously branching, with leaf scars on older shoots. Leaves trimorphic, dorsal leaves in longitudinal rows on surface of shoot or rosulate, caducous, linear or oblong, 0.5–1 × ca. 0.5 mm; leaves in rosettes 2.5–3.5 × ca. 0.3 mm, linear-oblanceolate, outer leaves shorter; marginal leaves fimbriate, linear-lanceolate, 0.6–4 × ca. 0.4 mm. Flower bud contained in leafy cupule, leaves linear, 1.5–3.5 mm long. Flowers solitary, scattered on dorsal surface, with ruptured cupules at base; pedicel 1.5–2 mm long; calyx 3-lobed, membranous, 1–1.5 mm long; stamens 3, separate, alternate calyx lobes, 1.5–2 mm long, as long as pistil; anthers oblong, 0.5–0.7 mm long. Ovary 1, 3-locular, obovoid-ellipsoid, 1.2–1.5 × 0.8–1.1 mm; ovules 62–80 per locule, placentation axile; stigmas 3, free, ovate, papillate; capsules trigonous, 0.8–1.2 × 1.5–2 mm, ribs 9, stalk 1.5–5 mm long, dehiscing by 3 valves; dried seeds 0.14–0.21 × 0.07–0.12 mm.

Distribution. Endemic to northeastern Thailand (Loei and Chaiyaphum Provinces); 270–400 m elevation. This is the first record from Loei Province, the northernmost distribution of *Dalzellia* of Thailand. *Dalzellia kailarsenii* was described from Chaiyaphum Province south of Loei (Kato 2004). The occurrence in Loei is in the Forest Protection Ban Namthob Unit, approximately 150 km distance from the population in Chaiyaphum Province (Tardtone waterfall). The distribution range in Loei Province is 3 m^2. The habitat in Loei is threatened by pollutants and disturbance.

Conservation status. Critically Endangered [CR B1ab(i,ii,iii)+2ab(i,ii,iii)].

Specimens examined. NE Thailand, Loei Province: Forest Protection Ban Namthob Unit, Wang Saphung dist., 397 m alt., 17°15′37.4″ N, 101°34′51.2″ E, 14 Feb. 2010, ster. fl. fr., *P. Werukamkul & S. Koi TPK23*; Phu Luang wildlife sanctuary, Wangsaphung dist., 290 m alt., 17°15'39.1" N, 101°34'53.7" E, sterile, fl. fr., 16 Jan. 2008, *S. Koi, R. Fujinami, N. Katayama & T. Wongprasert TKF-03*; Phu Luang wildlife sanctuary, Wangsaphung dist., 295 m alt., 17°15'20.2" N, 101°34'38.9" E, sterile, fl. fr., 16 Jan. 2008, *S. Koi, R. Fujinami, N. Katayama & T. Wongprasert TKF-05*.

2. **Terniopsis heterostaminata** Werukamkul, Ampornpan, Koi & M. Kato, **sp. nov.**—Fig. 2.

Among congeners, *Terniopsis heterostaminata* differs from the phylogenetically closely related *T. malayana* in the stamens equal to the ovary and usually 2, rarely 3, one shorter than the other and apparently abortive, and less distinctly differing in the ramuli shorter, commonly 2- rarely 3-times branched; leaves oblique; sterile ramuli associated with flower longer and pedicel longer.

Typus: Northeastern Thailand, Loei Prov.: Gaeng Ree, Dan Sai dist., 373 m alt., 17°28′30.2″ N, 101°07′52.9″ E, 13 Feb. 2010, *P. Werukamkul & S. Koi TPK05* (holo- BKF; iso- TNS).

Root creeping, monopodially branched, flattened-subcylindrical, 0.4–1.6 mm wide; ramuli on both flanks of root, 1- or 2- (or 3)-branched near base, 1.4–14 mm long; leaves borne on ramuli, tristichous, elliptic-oblong, lateral leaves in 2 ranks, slightly larger than middle leaves, 0.5–1.5 × 0.3–0.8 mm, middle leaves in 1 rank, 0.2–1.6 × 0.3–0.7 mm. Flowering shoot usually with a single flower and 1–4 associated ramuli; ramuli 1.2–15 mm long; pedicel 1.7–7 mm long; bracts 2, broadly ovate-elliptic, 0.8–1.8 × 0.3–2 mm. Calyx membranous, ovoid, obtuse, (0.5–)1–1.8 mm long, 3-lobed 1/3 to base. Stamens 2 (rarely 3), (1.1–)1.5–3 mm long, as long as or longer than pistil, one developing later than the other and somewhat abortive; anther oblong, 0.6–1.2 × 0.3–0.7 mm. Ovary obovoid, 0.9–1.5 × 0.5–1.2 mm, 3-locular; ovules (17–)20–38 per locule, borne on entire surface; stigmas 3, separate, cristate, 0.2–0.5 mm long; capsule obovoid, 0.9–1.6 × 0.6–1.1 mm; ribs 9; stalk 2.5–8 mm long; seeds 0.21–0.27 × 0.08–0.1 mm. Fruits and seeds maturing by late January.

Distribution. Endemic to Loei Province; in five adjacent rapids just a few meters apart in Hueang River and one rapid in San River; 370–

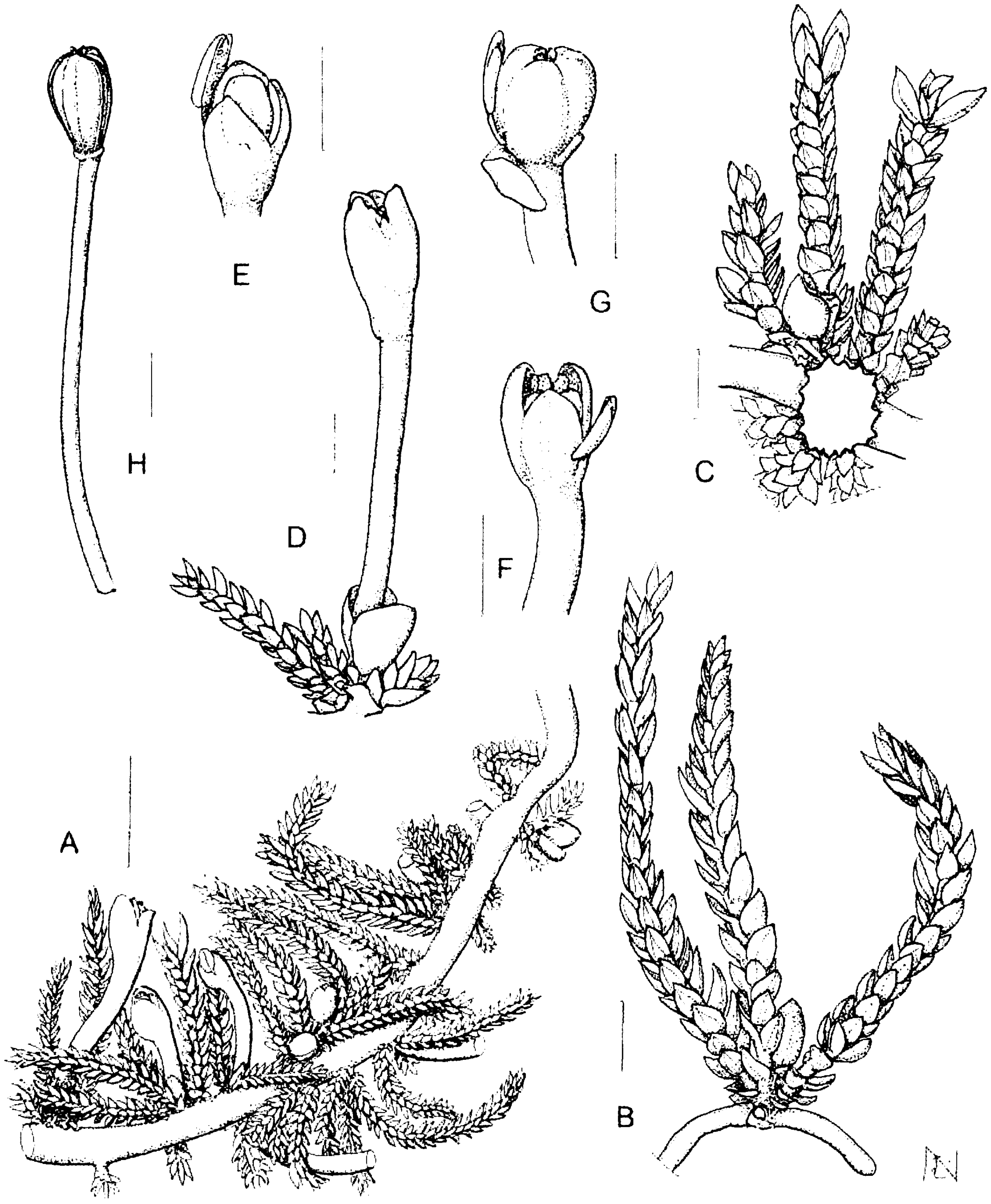

FIG. 2. *Terniopsis heterostaminata* (A–C, E–G, *P. Werukamkul & S. Koi TPK05*; D, H, *P. Werukamkul & S. Koi TPK11*). A: Flattened subcylindrical root with vegetative and flowering ramuli on flank. B: Dorsal view of branched ramuli with leaves in 3 ranks. C: Ventral view of branched ramuli and holdfast on ventral surface of root. D: Young flower subtended with 2 bracts at base and associated with ramuli. E, F: Flowers with 2 stamens, one developed earlier than the other. G: Young fruit. H: Fruit with 3 lobes and 9 ribs. Scale bars = 3 mm for A; 1 mm for B–H.

450 m elevation; distribution range 16 km^2. The habitat is degraded and the populations are declining. It is possible that *Terniopsis heterostaminata* occurs elsewhere.

Conservation status. Critically Endangered [CR B1ab(i,ii,iii)+2ab(i,ii,iii)].

Other specimens examined. NE Thailand, Loei Province: Gaeng Tham, Dan Sai dist., 418 m alt., 17°28′22″ N, 101°07′54.4″ E, 11 Dec. 2009, ster. fl., *P. Werukamkul & L. Ampornpan TWA40, TWA41*, 13 Feb. 2010, ster. fl. fr., *P. Werukamkul & S. Koi TPK03*; Gaeng Ree, Dan Sai dist., 373 m alt., 17°28′30.2″ N, 101°07′52.9″ E, 11 Dec. 2009, ster. fl., *P. Werukamkul & L. Ampornpan TWA44*; Gaeng Ladkrai, Dan Sai dist., 441 m alt., 17°28′54.4″ N, 101°08′48.8″ E, 11 Dec. 2009, ster., *P. Werukamkul & L. Ampornpan TWA47, TWA48*, 13 Feb. 2010, ster. fl. fr., *P. Werukamkul & S. Koi TPK08*; Gaeng Kongom, Dan Sai dist., 442 m alt., 17°29′0.3″ N, 101°08′4.3″ E, 11 Dec. 2009, ster., *P. Werukamkul & L. Ampornpan TWA46*, 13 Feb. 2010, ster. fl. fr., *P. Werukamkul & S. Koi TPK09*; Gaeng Gwang, Dan Sai dist., 445 m alt., 17°29′0.3″ N, 101°08′4.4″ E, 11 Dec. 2009, ster. fl., *P. Werukamkul & L. Ampornpan TWA45*, 13 Feb. 2010, ster. fl. fr., *P. Werukamkul & S. Koi TPK11*; Gaeng Tha Lad, Phu Ruea dist., 397 m alt., 17°29′47.1″ N, 101°15′36.1″ E, 13 Feb. 2010, ster. fl. fr., *P. Werukamkul & S. Koi TPK12*.

Notes. Among its congeners in Thailand, *Terniopsis heterostaminata* is most similar to *T. malayana*. It belongs to the *T. malayana* clade, which includes *T. brevis* and *T. minor* (Koi *et al.* 2012). *Terniopsis heterostaminata* occurs in the monsoon region of northeastern Thailand, an area with three distinct seasons; *T. malayana* occurs in the Malay Peninsula in a tropical climate.

3. **Terniopsis filiformis** Werukamkul, Ampornpan, Koi & M. Kato, **sp. nov.**—Fig. 3

Distinct from the congeners in the stigmas forked and filiform.

Typus: Northeastern Thailand, Loei Prov.: Gok-tab waterfall, Phu Luang dist., 505 m alt., 17°03′14.8″ N, 101°31′50″ E, 3 Mar. 2012, *P. Werukamkul & L. Ampornpan TWA218* (holo- BKF; iso- TNS).

Root creeping, monopodially branched, flattened-subcylindrical, 0.3–2 mm wide; ramuli 1–7, on both flanks of root, branched, 2–8 mm long; leaves tristichous on ramuli, elliptic-oblong, lateral leaves in 2 ranks, 0.5–2 × 0.5–1.1 mm, middle leaves in 1 rank, 0.5–1.5 × 0.4–1.9 mm, both types of leaves patent; flowering shoot usually with a single flower and 2–8 associated ramuli, 1.2–6.5 mm long; pedicel 1–2.9 mm long; bracts 2, broadly ovate-elliptic, 0.5–1.2 × 1–1.5 mm; calyx membranous, apex obtuse, 0.7–1.5 × 0.7–1.1 mm long, 3-lobed 3/4 to base; stamens 3, rarely 2, 1.1–2 mm long, as long as pistil, anther ellipsoid, 0.5–1 × 0.3–0.6 mm; ovary obovoid-ellipsoid, 0.9–1.7 × 0.7–1.2 mm, 3-locular, ovules 8–30 per locule, borne on entire surface of placenta; stigmas 3, separate, cristate when young, filiform and forked at anthesis, (0.2–)0.4–0.5(–1) mm long; capsule obovoid, 1–2 × 0.7–1 mm, stalk 1–2.2(–4) mm long, ribs 9.

Distribution. Endemic to Loei Province (Phu Luang District at 500–550 m elevation). It is possible that *Terniopsis filiformis* is distributed elsewhere. The species has been collected from two localities in the Loei River, one in Gok-tab waterfall and the other in a rapid, Gaeng Hua Wang Hai. It has not been seen in Gaeng Hua Wang Hai since January 2011 due to pollutants from trucking, agricultural effluents and recreational activities. The Gok-tab waterfall habitat is threatened by disturbance and pollutants introduced by visitors. The waterfall receives polluted water from the upstream Gaeng Hua Wang Hai. This threat results in anomalous flowers, which impact the reproduction. The species distribution range is 100 m^2.

Conservation status. Critically Endangered [CR B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)].

Other specimens examined. NE Thailand, Loei Province: Gok-tab waterfall, Phu Luang dist., 505 m alt., 17°03′14.8″ N, 101°31′50″ E 17 Jan. 2010, ster., *P. Werukamkul & L. Ampornpan TWA104*, 14 Feb. 2010, ster. fl. fr., *P. Werukamkul & S. Koi TPK25*; Gaeng Hua Wang Hai, Phu Luang dist., 539 m alt.,17°05′8.2″ N, 101°30′42.5″ E, 17 Jan. 2010, ster., *P. Werukamkul & L. Ampornpan TWA105*, 14 Feb. 2010, ster. fl. fr., *P. Werukamkul & S. Koi TPK27*.

Notes. Terniopsis filiformis is equivalent to *Terniopsis* 'Lao-Thai' subclade in Koi *et al.*'s (2012) tree. It is sister to the *Terniopsis sessilis* subclade, which includes *T. ubonensis* and an undescribed species from Laos (Koi *et al.* 2012, S. Koi and M. Kato, unpublished data), but differs

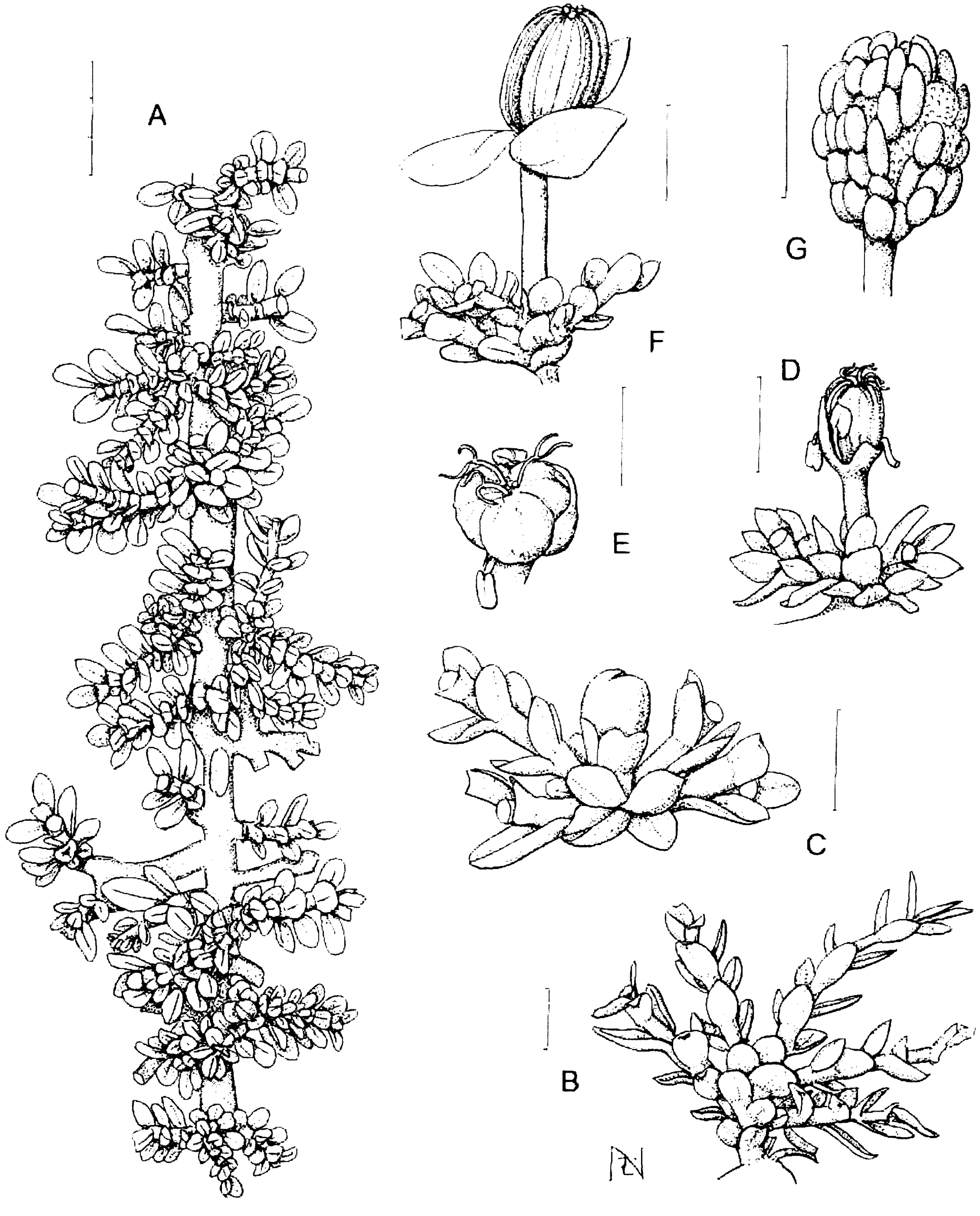

FIG. 3. *Terniopsis filiformis* (*P. Werukamkul & L. Ampornpan TWA218*). A: Branched flattened subcylindrical root with vegetative ramuli on flank. B: Dorsal view of branched ramuli with leaves in 3 ranks. C: Young flower subtended with 2 bracts at base and associated with ramuli. D: Flower associated with ramuli. E: Top oblique view of flower, showing 3-forked filiform stigmas. F: Young fruit. G: Ovules on septum (ovules fallen in empty space). Scale bars = 3 mm for A; 1 mm for B–G.

from the latter two species in having stamens as long as the ovary (vs. stamens longer in those species).

4. **Polypleurum pluricostatum** Koi & M. Kato in Kew Bull. 67(3) 340, f. 5, 2012.

Root prostrate, green, ribbon-like, 2–3.1 mm wide, 0.2–0.6 mm thick, attached to substratum by ventral holdfasts at intervals along length of root, dichotomously branched, with tufts of leaves on dorsal surface at sinuses of root branches; leaves to 6 per tuft, 4.5–45 mm long, base sheath-like, ovate, papillate, apex caudate; flowering shoots at sinuses of root branches, erect; bracts in 2 ranks, 2–4, base sheath-like, ovate, papillate, apex caudate, 9–32 mm long; spathella enclosing flower bud 1–2 mm long, papillate, ruptured near apex; flower pedicellate, pedicel 2.5–5 mm long; tepals 2, on either side of stamen, linear, 1–1.5 mm long; stamen 1, 1.5–3.9 mm long, longer than pistil; ovary 1- or 2-locular, sessile, ellipsoid, 0.9–1.9 mm long, 0.6–1.5 mm wide; stigmas bifid, subequal, 0.40–1.5 mm long, ovules on entire surface of septum, 14–60 per locule; capsule ellipsoid, 1–2 × 0.5–1.2 mm, ribs 10–14, stalk 2.6–6 mm long; seeds 0.24–0.34 × 0.15–0.19 mm.

Distribution. Loei Province (Phu Ruea National Park, Phu Ruea District), 770–1,200 m elevation; north-central Laos, 700–750 m elevation. There are five adjacent localities a few meters apart in a single stream in Phu Ruea National Park in Loei Province and there is a single locality in Laos (Koi & Kato 2012). The species distribution range in Loei is 15 km^2. The population in Loei is not declining.

Conservation status. Near Threatened (NT B1a+2a).

Specimens examined. NE Thailand, Loei Province: Huai Toei waterfall, Phu Ruea natl. park, Phu Ruea dist., 1,197 m alt., 17°30′10.6″ N, 101°20′13″ E, 15 Jan. 2010, ster. fl., *P. Werukamkul & L. Ampornpan TWA103*, 14 Feb. 2010, fr., *P. Werukamkul & S. Koi TPK17*; Hin Sam Chan waterfall, Phu Ruea natl. park, Phu Ruea dist., 1,152 m alt., 17°30′0.2″ N, 101°20′9″ E, 15 Jan. 2010, ster. fl., *P. Werukamkul & L. Ampornpan TWA99, TWA100, TWA101*, 14 Feb. 2010, fr., *P. Werukamkul & S. Koi TPK18*; Lued Pob waterfall, Phu Ruea natl. park, Phu Ruea dist., 1,143 m alt., 17°30′0.2″ N 101°20′9.1″ E, 15 Jan. 2010, ster. fl., *P. Werukamkul & L. Ampornpan TWA102*, 14 Feb. 2010, fr., *P. Werukamkul & S. Koi TPK19*; Lad Hin Taek, Phu Ruea natl. park, Phu Ruea dist., 1,043 m alt., 17°29′42.7″ N, 101°20′2.9″ E, 18 Jan. 2010, fl. fr., *P. Werukamkul & L. Ampornpan TWA110*, 14 Feb. 2010, fr., P. *Werukamkul & S. Koi TPK20*; Lad Hin-huai-khum-lek, Phu Ruea natl. park, Phu Ruea dist., 961 m alt., 17°29′29.6″ N, 101°20′0.7″ E, 18 Jan. 2010, fl. fr., *P. Werukamkul & L. Ampornpan TWA111*; Huai Phai waterfall, Phu Ruea natl. park, Phu Ruea dist., 770 m alt., 17°28′49.4″ N, 101°20′10.2″ E, 18 Jan. 2010, fl. fr., *P. Werukamkul & L. Ampornpan TWA112*, 14 Feb. 2010, fr., *P. Werukamkul & S. Koi TPK21.*

Notes. Polypleurum pluricostatum is similar to most other congeners in the ribbon-like root with tufts of leaves (i.e., devoid of long stems) and flowers subtended by simple bracts and with single stamens and ovaries and two tepals, but differs in the 10–14-ribbed capsules (compared with usually 8–12-ribbed capsules in the other congeners). *Polypleurum pluricostatum* differs also from *P. phuwuaense* M. Kato with up to 14 ribs per capsule, by the shorter stalk of the capsule (3–6 mm long vs. 10–20 mm in *P. phuwuaense*) and the number of ovules (14–60 per locule vs. 10–20). It is most closely related to *P. longicaule* from Udon Thani, northeastern Thailand, with remarkably long branched shoots (Koi & Kato 2012).

5. **Hanseniella heterophylla** C. Cusset in Bull. Mus. Natl. Hist. Nat. Paris, 4^e Sect B. Adansonia 14(1): 36, f. 6, 1992; Kato in Acta Phytotax. Geobot. 55(3): 139, f. 2, 2004.

Root crustaceous, 0.1–0.6 mm thick, irregularly lobed, lobes 5–17 mm wide, with tufts of leaves scattered on dorsal surface; leaves 4–7 per tuft, linear, needle-like, 2–3 mm long, dark red, base sheath-like. Flowering shoots 2.5–3.5 mm long before anthesis, erect or slightly suppressed; bracts thick, 4-ranked, 4–6 per rank, dimorphic, ventral bracts in 2 ranks, oblong 1–2.5 × 1–1.7 mm, 2-lobed 1/2 to base, lobes obtuse or bluntly rounded, dorsal bracts in 2 ranks, simple, deltoid or subacute, abaxially carinate, 1–2.1 × 0.4–1 mm. Spathella enclosing flower bud thin, with 3 thick ridges in upper portion, spathella opening by rupturing on dorsal surface at base of ridges before anthesis, with distal portion occasionally hanging on ventral surface. Flower terminal, solitary; pedicel 0.5–2 mm long; tepals 2, on either side of common andropod, linear, 2–3.5 mm long; stamens 2, 3–5 mm long, branched near middle, common andropod 1.5–3 mm long, exceeding pistil; ovary 1, 2-locular, ellipsoid, slightly flattened, 1–2.5 × 0.6–1 mm; gynophore 0.3–2 mm long; stigmas bifid, forked near base, acute, equal or subequal, 0.5–1.6 mm long; ovules, 4–8 per locule, large, ca. 0.5 × 0.2–0.3 mm, on marginal surface of septum except in sterile middle area; capsule ellipsoid, 1.7–2.7 × 0.8–1.2 mm, ribs 12–14, stalk 2–4 mm long; dried seeds 0.66–0.84 × 0.22–0.42 mm.

Distribution. Endemic to northern and northeastern Thailand, from western Loei Province to northeastern Phitsanulok Province. The distribution range is 1,644 km^2. There are three adjacent localities in the San River and one locality in the Hueang River in Loei, and six localities along a river in Phitsanulok. The species is declining due to disturbances and pollutants.

Conservation status. Endangered [EN B1ab(i,ii,iii)+2ab(i,ii,iii)].

Specimens examined. NE Thailand, Loei Province: Gaeng Gliang, Phu Ruea dist., 591 m alt., 17°25′53.9″ N, 101°16′48.2″ E, 5 Dec. 2009, ster. fl. fr., *P. Werukamkul & L. Ampornpan TWA01, TWA02, TWA03, TWA04, TWA05, TWA06, TWA07, TWA08, TWA09, TWA10, TWA11*, 13 Feb. 2010, fr., *P. Werukamkul & S. Koi TPK15*; Gaeng Tha Lad, Phu Ruea dist., 397 m alt., 17°28′47.1″ N, 101°15′59.9″ E, 5 Dec. 2009, fl. fr., *TWA12, TWA13*, 13 Feb. 2010, fr., *P. Werukamkul & S. Koi TPK13*; Gaeng Pak Nao, Phu Ruea dist., 485 m alt., 17°28′3.7″ N, 101°15′59.9″ E, 12 Dec. 2009, fl. fr., *P. Werukamkul & L. Ampornpan TWA53, TWA54*; Gaeng Tad Kha, Thali dist., 397 m alt., 17°34′8.0″ N, 101°14′52.7″ E, 12 Dec. 2009, fl. fr., *P. Werukamkul & L. Ampornpan TWA55.*

6. **Thawatchaia trilobata** M. Kato, Koi & Y. Kita in Acta Phytotax. Geobot. 55(2): 66, f. 1, 2, 3A–C, 2004; Kato in Acta Phytotax. Geobot. 55(3): 142, f. 4, 2004.

Root crustaceous, green, 0.2–0.6 mm thick, irregularly lobed, lobes 5–7 mm wide, with tufts of leaves scattered on dorsal surface; leaves needle-like, 2–8 per tuft, 1–2 mm long. Flowering shoots 2.2–4 mm long before anthesis, scattered on dorsal surface, appressed; bracts thick, 2-ranked, 4–6 per rank, trilobed, 0.5–3 × 1.4–2 mm, median lobe 1.5–3 mm long, usually longer than two laterals, middle and dorsal lobes acute, ventral lobe obtuse, shortest, upper bracts gradually larger. Spathella enclosing flower bud thin, apex mucronate, mucrone 0.2–0.5 mm long, rupturing irregularly. Flower solitary, terminal, pedicel 0.6–1 mm long; tepals 2, on either side of stamen, 2.5–4 mm long, linear; stamens 2, 6–7 mm long, common andropod 2.5–4 mm long, forked above middle, as high as ovary or longer than ovary, exceeding pistil; ovary 1, 2-locular, flattened, ellipsoid, 2–3 × 1–1.5 mm, gynophore 1–1.7 mm long; ovules large, 6–8 per locule, borne on marginal surface of septum except in sterile middle area; stigmas bifid above base, linear, equal or subequal, 0.5–2 mm long; capsule ellipsoid, 2.5–3.5 × 1–1.5 mm, ribs 8–10, stalk 2–3 mm long; seeds 0.58–0.65 × 0.31–0.41 mm.

Distribution. Endemic to northern and northeastern Thailand (Chiang Mai and Loei Provinces). *Thawatchaia trilobata* was collected from four adjacent rapids in the Hueang River and in one rapid in the San River in Loei Province. It has been totally lost from all localities in Loei since December 2010. There is currently one occurrence in Doi Inthanon National Park, Chiang Mai (Kato 2004).

Conservation status. Critically Endangered [CR B1ab(i,ii,iii)+2ab(i,ii,iii)].

Specimens examined. NE Thailand, Loei Province: Gaeng Khem, Dan Sai dist., 418 m alt., 17°28′22.7″ N, 101°08′48.2″ E, 9 Dec. 2009, ster. fl. buds, *P. Werukamkul & L. Ampornpan TWA38*, 26 Dec. 2009, fl. fr. *P. Werukamkul & L. Ampornpan TWA57, TWA58*, 12 Feb. 2010, fr. *P. Werukamkul & S. Koi TPK02*; Gaeng Tham, Dan Sai dist., 418 m alt., 17°28′22.0″ N, 101°07′54.4″ E, 9 Dec. 2009, ster. fl. buds, *P. Werukamkul & L. Ampornpan TWA39*, 26 Dec. 2009, fl. fr. *P. Werukamkul & L. Ampornpan TWA59*, 13 Feb. 2010, fr. *P. Werukamkul & S. Koi TPK04*; Gaeng Ladkrai, Dan Sai dist., 441 m alt., 17°28′50.1″ N, 101°08′48.8″ E, 11 Dec. 2009, fl. buds, *P. Werukamkul & L. Ampornpan TWA49*; Gaeng Ree, Dan Sai dist., 373 m alt., 17°28′30.2″ N, 101°07′52.9″ E, 11 Dec. 2009, fl. *P. Werukamkul & L. Ampornpan TWA50*, 13 Feb. 2010, fl. fr. *P. Werukamkul & S. Koi TPK07*; Gaeng

Tha Lad, Phu Ruea dist., 397 m alt., 17°29′47.1″ N, 101°15′36.1″ E, 13 Feb. 2010, fl. fr. *P. Werukamkul & S. Koi TPK14.*

Notes. Thawatchaia trilobata is sister to the two species of *Hanseniella* in the *Hydrobryum* clade (Koi & Kato 2010). *Thawatchaia* shares lobed bracts with *Hanseniella*, but differs in the uniform bracts. *Thawatchaia* is also similar to *Hydrobryum* in the uniform bracts but differs in the trilobed bracts.

7. **Hydrobryum japonicum** Imamura in Bot. Mag. Tokyo 42: 376, 1928; *ibid.* 43: 332, 1929; Cusset in Bull. Mus. Natl. Hist. Nat. Paris, 4^e Sect B. Adansonia 14(1): 46, 1992, *p.p.*; Kato & Kita in Acta Phytotax. Geobot. 54(2): 95, 2003; Kato in Acta Phytotax. Geobot. 55(3): 157, 2004; Bull. Natl. Mus. Nat. Sci., Ser. B. 34(2): 69, 2008; *ibid.* 37(1): 6, 2011.

Root crustaceous, 0.2–0.5 mm thick, irregularly lobed, lobes 5–13 mm wide, with tufts of leaves scattered on dorsal surface; leaves 2–8 per tuft, needle-like, 1.5–4 mm long. Flowering shoots appressed, 1.4–2.5 mm long before anthesis; bracts uniform, smooth, 2-ranked, 2–4, ovate, simple, 1–1.5 × 0.4–1 mm; spathella enclosing flower bud smooth, irregularly rupturing near apex at anthesis. Flower solitary, terminal, subsessile, pedicel 0.2–0.6 mm long; tepals 2, on either side of stamen, 1.5–2.5 mm long, linear; stamens 2, 2–4.5 mm long, forked near middle, common andropod 1–2.1 mm long, much longer than pistil; ovary 1, 2-locular, ellipsoid, flattened, 1.1–2 × 0.9–1.2 mm, gynophore 0.3–0.8 mm long; ovules on marginal surface of septum, 14–16 per locule; stigmas bifid above base, 0.5–0.7 mm long, subulate, equal, 0.5–1.5 mm long; capsule ellipsoid, 1.2–2.2 mm long, 0.9–1.3 mm wide, ribs 10–14, stalk 0.6–1.5 mm long; seeds 0.27–0.45 × 0.12–0.24 mm.

Distribution. Northern, northeastern, and southwestern Thailand, more common in Loei than previously thought (Kato 2004); southwestern Japan, south-central China, northern Myanmar, northern Vietnam. This is the most widely distributed species of Podostemaceae in East and Southeast Asia. There are four occurrences in Loei, which are all protected areas.

Conservation status. Least Concern.

Specimens examined. NE Thailand, Loei Province: Tadnoi waterfall, Forest Protection Ban Namjan Unit, Wang Saphung dist., 430 m alt., 17°20′57.7″ N, 101°33′23.7″ E, 28 Dec. 2009, fl. fr., *P. Werukamkul & L. Ampornpan TWA71, TWA72, TWA73*; Loei-nga River, Phu Luang dist., 533 m alt., 17°04′52.2″ N, 101°29′44.7″ E, 30 Dec. 2009, ster. fl. fr., *P. Werukamkul & L. Ampornpan TWA79, TWA80, TWA81, TWA82*; Gaeng Namsai, Phu Luang wildlife res., Phu Luang dist., 513 m alt., 17°10′25.4″ N, 101°28′14.9″ E, 30 Dec. 2009, fl. fr., *P. Werukamkul & L. Ampornpan TWA85*; Gaeng Hom-chang Phu Luang wildlife res., Phu Luang dist., 505 m alt., 17°10′13.9″ N, 101°28′15″ E, 30 Dec. 2009, ster. fl. buds, *P. Werukamkul & L. Ampornpan TWA86.*

8. **Hydrobryum loeicum** M. Kato in Acta Phytotax. Geobot. 55(3): 150, f. 9, 2004.

Root crustaceous, 0.2–0.5 mm thick, irregularly lobed, 6–17 mm wide, with tufts of leaves scattered on dorsal surface; leaves 1–3 per tuft, needle-like, 0.5–3.6 mm long. Flowering shoots appressed, 1.6–3.5 mm long before anthesis; bracts 2-ranked, 2–6, ovate, 0.5–1.5 mm long, 0.3–1 mm wide, simple, apex obtuse, papillate. Spathella enclosing flower bud papillate, irregularly rupturing near apex at anthesis; flowers terminal, solitary, subsessile, pedicel 0.1–0.5 mm long; tepals 2, on either side of common andropod, linear, 1.5–4 mm long. Stamens 2, 3–5.9 mm long, forked 1/2–2/3 from base, common andropod 1.5–4 mm long or as long as or longer than ovary; ovary 1, 2-locular, flattened ellipsoid, 0.9–2 × 0.4–1 mm, gynophore 0.3–1 mm long; ovules large, on upper and lower marginal surface of septum, 4–11 per locule; stigmas 2, linear, acute, equal or subequal, 0.3–1 mm long; capsule ellipsoid, 1.2–2 × 0.6–1.2 mm, ribs 16–20, stalk 1–2 mm long; dried seeds 0.5–0.8 × 0.2–0.3 mm.

Distribution. Endemic to Loei Province (Hueang River) at 370–700 m elevation; locally abundant. The species has been lost at two localities and has decreased in abundance outside Phu Suan Sai National Park. There are currently 19 localities in the Hueang River. The species distribution range is 220 km^2.

Conservation status. Endangered [EN B1ab(i,ii,iii)+2ab(i,ii,iii)].

Specimens examined. NE Thailand, Loei Province: Khanbundai waterfall, Na Haeo dist., 591 m alt., 17°25′54″ N, 101°16′48.2″ E, 7 Dec. 2009, ster., *P. Werukamkul & L. Ampornpan TWA19*; Tadtone waterfall, Na Haeo dist., 503 m alt., 17°29′17.9″ N, 101°03′2.2″ E, 7 Dec. 2009, ster., *P. Werukamkul & L. Ampornpan TWA20*; Tadnokgok, Phrae River, Na Haeo dist., 521 m alt., 17°29′9″ N, 101°02′48.5″ E, 7 Dec. 2009, ster. fl. fr., *P. Werukamkul & L. Ampornpan TWA21, TWA22, TWA23*; Had Hinkhon, Na Haeo dist., 433 m alt., 17°29′10″ N, 101°06′21.4″ E, 7 Dec. 2009, ster. fl. fr., *P. Werukamkul & L. Ampornpan TWA24, TWA25*; Gaeng Khonkan, Na Haeo dist., 476 m alt., 17°29′2.9″ N, 101°06′36″ E, 7 Dec. 2009, fl. fr., *P. Werukamkul & L. Ampornpan TWA26*; Gaeng Wangpo, Na Haeo dist., 480 m alt., 17°29′5.7″ N, 101°06′37.5″ E, 7 Dec. 2009, fl. fr., *P. Werukamkul & L. Ampornpan TWA27*; Hueang-nga waterfall, Na Haeo dist., 618 m alt., 17°34′17.1″ N, 100°58′3.3″ E, 8 Dec. 2009, ster. fl., *P. Werukamkul & L. Ampornpan TWA33, TWA34*; Changtok waterfall, Na Haeo dist., 661 m alt., 17°28′34.9″N, 100°58′23.0″E, 8 Dec. 2009, ster., *P. Werukamkul & L. Ampornpan TWA35*; Khring waterfall, Na Haeo dist., 615 m alt., 17°34′17.0″N, 100°58′32.6″E, 8 Dec. 2009, ster. fl., *P. Werukamkul & L. Ampornpan TWA36*; Wangtad waterfall, Na Haeo dist., 695 m alt., 17°28′37.1″ N, 100°57′33.8″ E, 8 Dec. 2009, ster. fl., *P. Werukamkul & L. Ampornpan TWA37*; Gaeng Kon-gom, Dan Sai dist., 442 m alt., 17°29′0.3″ N, 101°08′4.3″ E, 11 Dec. 2009, fl., *P. Werukamkul & L. Ampornpan TWA51*, 13 Feb. 2010, fl. fr., *P. Werukamkul & S. Koi TPK10*; Gaeng Ree, Dan Sai dist., 373 m alt., 17°28′30.2″ N, 101°07′52.9″ E, 11 Dec. 2009, fl. *P. Werukamkul & L. Ampornpan TWA52*, 13 Feb. 2010, fl. fr., *P. Werukamkul & S. Koi TPK06*; Gaeng Conpueng, Dan Sai dist., 442 m alt., 17°28′56.8″ N, 101°07′10.4″ E, 27 Dec. 2009, fl., *P. Werukamkul & L. Ampornpan TWA62*; Gaeng Huai-sog, Dan Sai dist., 460 m alt., 17°28′52.6″ N, 101°07′6.2″ E, 27 Dec. 2009, fl., *P. Werukamkul & L. Ampornpan TWA63, TWA64*; Gaeng Krabi, Dan Sai dist., 457 m alt., 17°28′42.7″ N, 101°06′48.5″ E, 27 Dec. 2009, ster. fl., *P. Werukamkul & L. Ampornpan TWA65*; Gaeng Panamgong, Na Haeo dist., 448 m alt., 17°30′26.4″ N, 101°05′26.9″ E, 27 Dec. 2009, fl. fr., *P. Werukamkul & L. Ampornpan TWA66*; Gaeng Chang, Na Haeo dist., 513 m alt., 17°10′25.4″ N, 101°28′14.9″ E, 1 Jan. 2010, fl., *P. Werukamkul & L. Ampornpan TWA88*; Gaeng Wang-O, Na Haeo dist., 587 m alt., 17°34′5.8″ N, 100°58′53.3″ E, 1 Jan. 2010, fl. buds, fl. fr., *P. Werukamkul & L. Ampornpan TWA89, TWA90*; Gaeng Wangpalat, Na Haeo dist., 581 m alt., 17°34′3.2″ N, 100°58′58″ E, 1 Jan. 2010, ster. fl. buds, fl., *P. Werukamkul & L. Ampornpan TWA91, TWA92, TWA93*; Gaeng Gone, Na Haeo dist., 477 m alt., 17°31′44.2″ N, 101°02′54.4″ E, 2 Jan. 2010, ster. fl. buds, fl. fr., *P. Werukamkul & L. Ampornpan TWA94, TWA95*; Gaeng Khane, Na Haeo dist., 475 m alt.,17°31′46.9″ N, 101°02′47.5″ E, 2 Jan. 2010, fl. fr., *P. Werukamkul & L. Ampornpan TWA96*.

9. **Hydrobryum vientianense** (M. Kato & Fukuoka) Koi & M. Kato in Kew Bull. 67(3) 349, f. 10, 2012—*Diplobryum vientianense* M. Kato & Fukuoka in Acta Phytotax. Geobot. 53(2): 115, 2002.

Root crustaceous, 0.1–0.6 mm thick, irregularly lobed, lobes 5.5–22 mm wide, with tufts of leaves scattered on dorsal surface; leaves 1–3 per tuft, needle-like, 0.5–2.5 mm long, scattered on dorsal surface of root. Flowering shoots appressed, 1.5–2.5 mm long; bracts uniform, 2-ranked, 2–6, ovate, apex obtuse, 0.5–1.6 × 0.5–1 mm, papillate; spathella enclosing flower bud papillate, apex obtuse, longitudinally rupturing at anthesis; flowers solitary, terminal, subsessile, pedicel 0.1–0.8 mm long; tepals 2, on either side of andropod, linear, 2–3.5 mm long, as long as, or longer than ovary; stamens 2, 2.7–6 mm long, common andropod 1.5–3.5 mm long, as long as or longer than ovary; ovary 1, 2-locular, ellipsoid, 1.1–2.5 × 0.5–1.5 mm, gynophore 0.5–1.7 mm long, ovules 8–23 per locule, on entire septum surface except on small lower central area or on marginal surface; stigmas bifid, forked above base, subulate, pointed, curved, equal or subequal, 0.4–1.1 mm long; capsule ellipsoid, 1.5–2.5 × 0.8–1.5 mm, ribs 14–20, stalk 1–2 mm long; seeds 0.3–0.5 × 0.2–0.3 mm.

Distribution. Loei Province (Mon River and Loei River) at 390–560 m elevation; north-central Laos (Vientiane Prov.) at 100–250 m elevation. Five samples from Loei were analyzed in a recent phylogenetic study (Koi & Kato 2012, Fig. 1). The species has been lost in one of seven currently known localities in Loei. The species distribution range in Loei is 410 km^2.

Conservation status. Endangered [EN B1ab(i,ii,iii)+2ab(i,ii,iii)].

Specimens examined. NE Thailand, Loei Province: Gaeng Songkone, Dan Sai dist., 391 m alt., 17°15′11.7″ N, 101°08′22.2″ E, 26 Dec. 2009, ster. fl. buds. fl. fr., *P. Werukamkul & L. Ampornpan TWA42, TWA43*; Gok-tab waterfall, Phu Luang dist., 505 m alt., 17°03′14.8″ N, 101°31′50″ E, 29 Dec. 2009, ster. fl. buds, fl. fr., *P. Weru-*

kamkul & L. Ampornpan TWA74, TWA75, TWA76, 14 Feb. 2010, fl. fr., *P. Werukamkul & S. Koi TPK26*; Loei River (under the bridge at Ban Loei Wang Sai), Phu Luang dist., 528 m alt., 17°14′37.7″ N, 101°29′21.1″ E, 29 Dec. 2009, ster. fl. buds. fl., *P. Werukamkul & L. Ampornpan TWA77, TWA78*, 14 Feb. 2010, fl. fr., *P. Werukamkul & S. Koi TPK29*; Loei-nga waterfall, Phu Luang dist., 560 m alt., 17°05′7.7″ N, 101°31′4.9″ E, 30 Dec. 2009, fl. fr., *P. Werukamkul & L. Ampornpan TWA83, TWA84*; Gaeng Homchang, Phu Luang wildlife res., Phu Luang dist., 505 m alt., 17°10′13.9″ N, 101°28′15″ E, 30 Dec. 2009, fl. fr., *P. Werukamkul & L. Ampornpan TWA87*; Gaeng Hua Wang Hai, Phu Luang dist., 539 m alt., 17°05′8.2″ N, 101°30′42.5″ E, 17 Jan. 2010, fl. fr. *P. Werukamkul & L. Ampornpan TWA106*, 14 Feb. 2010, fl. fr., *P. Werukamkul & S. Koi. TPK28*; Lad Sonpin, Phu Luang dist., 547 m alt., 17°05′8.2″ N, 101°30′42.5″ E, 17 Jan. 2010, fl. buds fl. fr., *P. Werukamkul & L. Ampornpan TWA108, TWA109*; Forest Protection Ban Namthob Unit, Wang Saphung dist., 397 m alt., 17°15′37.4″ N, 101°34′51.2″ E, 14 Feb. 2010, ster. fl. fr., *P. Werukamkul & S. Koi TPK24*; Phu Luang wildlife sanctuary, Wangsaphung dist., 290 m alt., 17°15'39.1" N, 101°34'53.7" E, fl. fr., 16 Jan. 2008, *S. Koi, R. Fujinami, N. Katayama & T. Wongprasert TKF-02*; Phu Luang wildlife sanctuary, Wangsaphung dist., 295 m alt., 17°15'20.2" N, 101°34'38.9" E, fl. fr., 16 Jan. 2008, *S. Koi, R. Fujinami, N. Katayama & T. Wongprasert TKF-04*

Notes. As shown in the above list of synonymy, *Hydrobryum vientianense* was first described as a species of *Diplobryum*, which is characterized by having about 20 ribs on the capsule (Kato & Fukuoka 2002). It is similar to *Diplobryum minutale* C. Cusset in the crustose root, but distinct from the other two congeners with cylindrical roots or shoots, suggesting heterogeneity of the genus *Diplobryum*. *Hydrobryum vientianense* is sister to *H. loeicum* (Koi & Kato 2010, 2012), but is not closely related to *H. minutale* (C. Cusset) Koi & M. Kato (S. Koi and M. Kato, unpublished data). *Hydrobryum minutale* was originally described as *Diplobryum minutale* C. Cusset, which is the type species of *Diplobryum*, is also nested within *Hydrobryum* (S. Koi and M. Kato, unpublished data).

10. **Hydrobryum phurueanum** Werukamkul, Ampornpan, Koi & M. Kato, **sp. nov.** —Fig. 4.

Similar to *H. bifoliatum* and *H. kaengsophense* in the unequal stigmas, but differing in the thin (0.1–0.3 mm) root, the caudate bract (to 10 mm), the papillate bract and spathella, and the andropod as long as or shorter than the pistil.

Typus: Northeastern Thailand, Loei Prov.: Gaeng Wang Gohia, Phu Luang wildlife sanctuary, Phu Ruea dist., 722 m alt., 17°21′32.9″ N, 101°23′59.9″ E, 13 Feb. 2010, *P. Werukamkul & S. Koi TPK16* (holo-BKF; iso-TNS).

Roots prostrate, crustaceous, 0.1–0.3 mm thick, irregularly lobed, lobes to 7 mm wide, with tufts of leaves scattered on dorsal surface; leaves 1–8 per tuft, needle-like, 2–6.5 mm long, base sheath-like, ca. 0.3 mm wide. Flowering shoots on dorsal surface, appressed, 1.5–2 mm long before anthesis; bracts 2-ranked, 2–10, papillate, base semicircular, sheathing, 0.5–0.7 × 0.5–0.8 mm, distal part caudate, to 13 mm long, lateral margins of bracts on each rank slightly overlapping; spathella enclosing flower bud papillate, rupturing longitudinally at anthesis; flower single, terminal; pedicel 0.2–0.6 mm long; tepals 2, on either side of andropod, linear 1.5–2.5 mm long; stamens 2 with andropod, branched near middle, 3.5–6 mm long, much longer than pistil, andropod as long as or shorter than ovary; ovary 1, 2-locular, ellipsoid, flattened, 1.5–2.5 × 0.5–0.9 mm, gynophore 0.5–0.9 mm long; stigmas bifid, forked ca. 0.3 mm above base, linear, recurved, subequal (longer stigma 0.5–1.1 mm long from branch point, shorter one 0.4–1 mm); ovules (8–)12–18(–26) per locule, on most of septum surface; capsule ellipsoid, 1.5–2.1 × 0.5–0.8 mm, ribs 10–16(–18), stalk 0.73–1.6 mm long; seeds 0.31–0.38 × 0.12–0.22 mm.

Distribution. Endemic to Loei Province (Phu Luang wildlife sanctuary) at 720 m elevation. *Hydrobryum phurueanum* has been collected from two rapids in a single stream in Phu Luang Wildlife Sanctuary. Its distribution range is 0.05 km^2. The population is not declining.

Conservation status. Near Threatened (NT B1a+2a).

Other specimens examined. NE Thailand, Loei Province: Gaeng Wang Gohia, Phu Luang wildlife sanctuary, Phu Ruea dist., 722 m alt., 17°21′32.9″ N, 101°23′59.9″ E, 6 Dec. 2009, ster. fl. fr., *P. Werukamkul & L. Ampornpan TWA14, TWA15, TWA16, TWA17*; Gaeng Songkone, Phu Luang wildlife sanctuary, Phu Ruea dist., 721 m alt., 17°15′1.7″ N, 101°29′14.6″ E, 6 Dec. 2009, ster. fl., *P.*

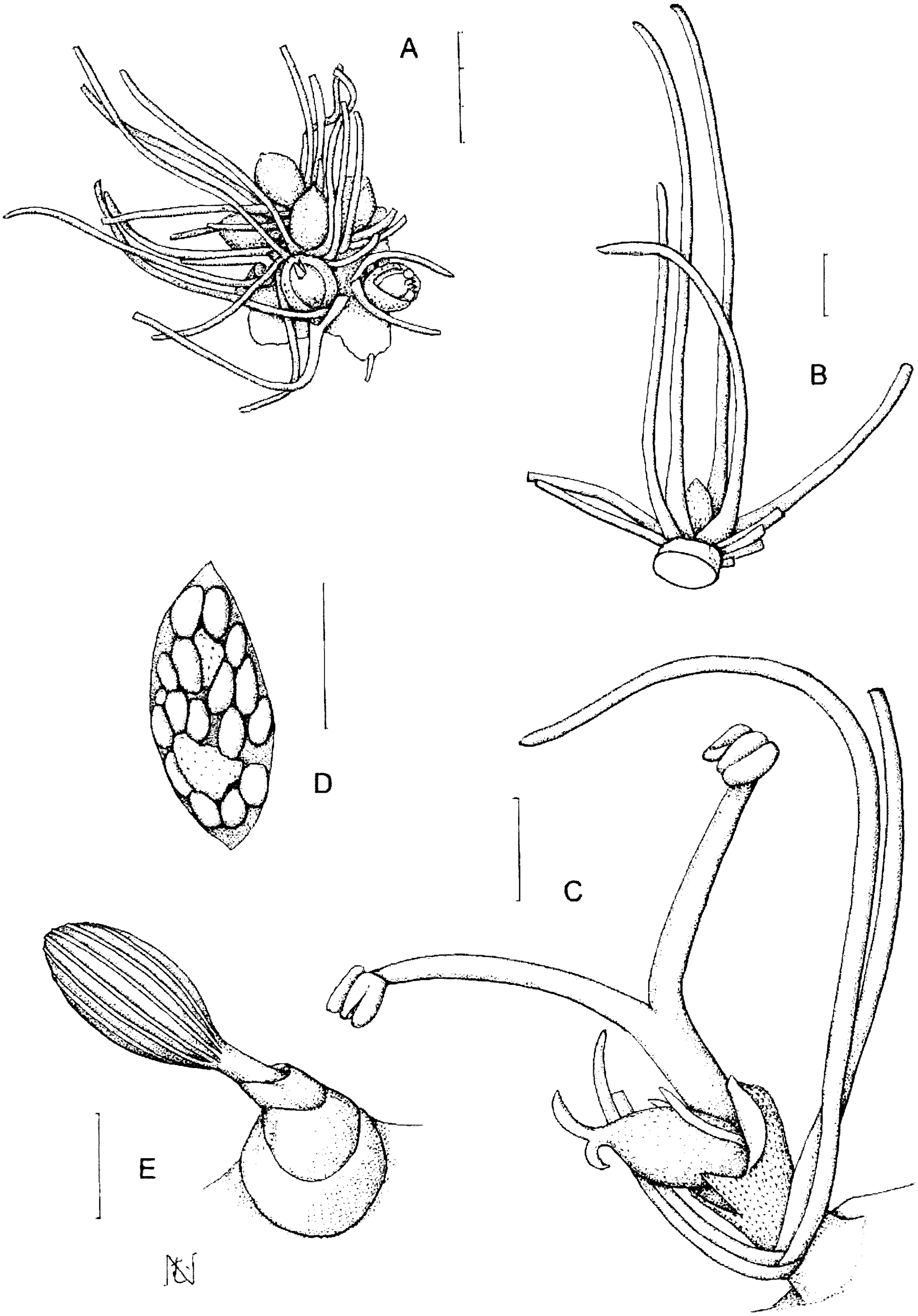

FIG. 4. *Hydrobryum phurueanum* (*P. Werukamkul & L. Ampornpan TWA14–17*). A: Young flowering shoots on crustose root. B: Young flowering shoot consisting of bracts and flower bud enclosed by spathella. C: Flower at anthesis with ruptured spathella and bracts; flower composed of 2 tepals, 2 stamens with common andropod and ovary. D: Ovules on ovary septum with sterile parts. E: Fruit with curved stalk enclosed by bract remains and 14-ribbed capsule. Scale bars = 3 mm for A; 1 mm for B–E.

Werukamkul & L. Ampornpan TWA18.

Notes. Hydrobryum phurueanum (*TPK16*) is nested within the clade of *Hydrobryum bifoliatum* and *H. kaengsophense*, and sister to *H. kaengsophense* (Koi & Kato 2012). The three species share the unequal stigmas, but to different degrees. The stigmas of *H. bifoliatum* and *H. kaengsophense* are markedly unequal, one being about half of the other, while the stigmas of *H. phurueanum* are subequal, which makes it similar to *H. tardhuangense*. *Hydrobryum phurueanum* clearly differs from those two in the much thinner root (0.1–0.25 mm), the semicircular sheathing base of the bract and its long caudate apex, papillate bract and spathella, and an andropod never exceeding the pistil. *Hydrobryum phurueanum* is sister to *H. kaengsophense* rather than to *H. bifoliatum* (Koi & Kato 2012). These two species are similar in the numbers of ovules and capsule ribs. Those characters are also seen in *H. tardhuangense*. *Hydrobryum phurueanum*, however, is clearly distinguished from *H. kaengsophense* in the thinner root and narrower lobes, in the absence of raised rings of root tissue surrounding tufts of leaves, the smaller bracts with long caudate apices, the stamen branched near the middle and not beyond the ovary, and the subequal stigmas. The prominent character of *H. phurueanum* separating it from its Thai congeners is the semicircular sheathing base of the bracts with the long caudate apex to 13 mm long.

11. **Hydrobryum varium** Ampornpan, Werukamkul, Koi & M. Kato, **sp. nov.** —Fig. 5.

Differs from *H. bifoliatum*, *H. kaensophense* and *H. tardhuangense* in the smaller bracts and the papillate bracts and spathellas, and from *H. tardhuangense* in the thinner roots, the shorter leaves, the acuminate bracts, the more ovules per locule, and the longer pedicels.

Typus: Northeastern Thailand, Loei Prov.: Haui Phai waterfall, Phu Ruea natl. park, Phu Ruea dist., 770 m alt., 17°28′49.4″ N, 101°20′10.2″ E, 14 Feb. 2010, *P. Werukamkul & S. Koi TPK22* (holo- BKF; iso- TNS).

Roots crustaceous, ca. 0.1 mm thick, irregularly lobed, with tufts of leaves scattered on dorsal surface; leaves 1–3 per tuft, surrounded by raised rings of root tissue, 1.5–2 mm long. Flowering shoots dorsal, appressed or slightly oblique, 1.4–2 mm long before anthesis; bracts 2-ranked, 2–4, base deltoid, sheath-like, 0.3–0.5 mm wide, apex acuminate, 1.0–4.5 mm long, papillate; spathella enclosing flower bud oval, papillate, ruptured longitudinally at anthesis; flower 1, terminal, pedicel 0.6–2 mm long; tepals 2, on either side of andropod, linear, 1.6–2.6 mm long, lower than ovary; stamens 2, 4.6–6 mm long at anthesis, branched usually 2/3 or more from base, longer than ovary; ovary 1, 2-locular, ellipsoid, flattened, 1.5–2.5 × 0.8–1.2 mm, gynophore 0.5–1.6 mm long; stigmas bifid, forked ca. 0.3 mm above base, linear, recurved, subequal (longer stigma 0.6–1.4 mm long, shorter one 0.5–1.2 mm); ovules (11–)23–37 per locule, on most surface of septum; capsule ellipsoid, 1.5–2.8 × 0.8–1.2 mm, ribs 12–14, stalk 1.5–3 mm long; dried seeds 0.25–0.35 × 0.12–0.20 mm.

Distribution. Endemic to Loei Province (Haui Phai waterfall) at 770 m elevation. Known from only one occurrence in Phu Ruea National Park. The distribution range is 48 m^2. The population is not declining.

Conservation status. Near Threatened (NT B1a+2a).

Other specimens examined. NE Thailand, Loei Province: Haui Phai waterfall, Phu Ruea natl. park, Phu Ruea dist., 770 m alt., 17°28′49.4″ N, 101°20′10.2″ E, 18 Jan. 2010, ster. fl., *P. Werukamkul & L. Ampornpan TWA113, TWA114*.

Notes. Hydrobryum varium is similar to *H. bifoliatum*, *H. kaengsophense* and *H. tardhuangense* in the andropod longer than the pistil and the unequal stigmas, but differs in the smaller bracts and the papillate bract and spathella. The stigmas of *H. varium*, unlike in *H. kaengsophense*, are not so markedly unequal, but subequal as in *H. phurueanum* and *H. tardhuangense*. *Hydrobryum varium* shares the raised ring of root tissue around tufts of leaves and 12–14 ribs on the capsules with *H. kaengsophense*, but it is closely related to *H. tardhuangense* (as *Hy.* sp. *TPK22* in Koi & Kato 2012). It is distinguishable from *H. tardhuangense* by the thinner root, shorter leaves, presence of raised ring, slightly oblique flower buds, caducous bracts, papillate bracts and

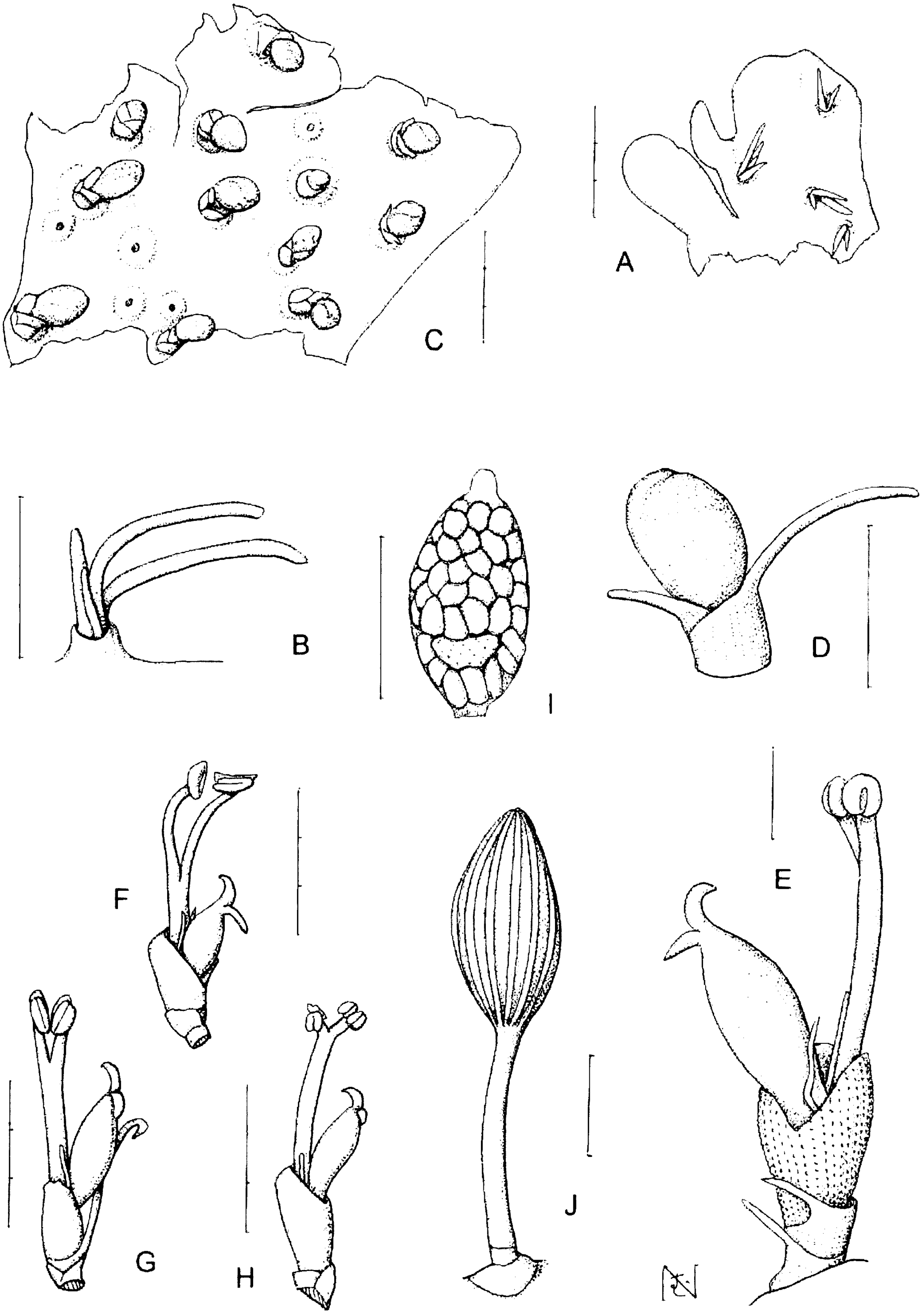

FIG. 5. *Hydrobryum varium* (*P. Werukamkul & L. Ampornpan TWA113-114*). A: Crustose root with tufted leaves on dorsal surface. B: Tufted leaves. C: Crustose root with flower buds on dorsal surface. D: Flower bud enclosed by spathella subtended by bracts. E: Flower at anthesis with ruptured spathella subtended by bracts. F–H: Flowers with variously long common andropods. F: stamen branched around middle; G: stamen branched below apex; H: stamen branched near apex. I: Ovules on ovary septum with sterile part. J. Fruit with 12-ribbed, stalked capsule. Scale bars = 3 mm for A, C, F–H; 1 mm for B, D, E, I, J.

spathellas, more ovules per locule, and longer capsule stalk. *Hydrobryum varium* is distinguished from other congeners by the spathella oval, ovules 23–37 per locule, capsule-stalk longer, and bracts small relative to the flower at anthesis.

12. **Hydrobryum tardhuangense** M. Kato in Acta Phytotax. Geobot. 55(3): 148, f. 7, 2004.

Root crustaceous, 0.2–0.4 mm thick, irregularly lobed, 6–14 mm wide, with tufts of leaves scattered on dorsal surface; leaves 2–6 per tuft, needle-like, base sheath-like, 3–7 mm long. Flowering shoots appressed, scattered on dorsal surface, 1.5–2.2 mm long before anthesis; bracts uniform, subpapillate, in 2 ranks, 2–6, deltoid, apex acuminate, 1.2–3.5 × 1–1.6 mm, margin slightly reflexed; spathella enclosing flower bud, subpapillate, ruptured longitudinally at anthesis; flower 1, terminal, subsessile; pedicel 0.3–0.7 mm long; tepals 2, on either side of common andropod, linear,1.5–3 mm long; stamens 2, 3–4.5 mm long after anthesis, common andropod 1.5–3.2 mm long, forked nearly 2/3 from base, higher than ovary; ovary 1, 2-locular, flattened, ellipsoid, 1.5–2 mm long, 0.5–1 mm wide, gynophore 0.4–0.6 mm long; ovules 11–19 per locule, on marginal surface of septum, sometime with 1 or few additional ovules in upper center; stigmas bifid, linear, curved, subequal, ventral stigma wider and thicker than dorsal stigma; capsule 1.5–2.2 × 0.7–1 mm, ellipsoid, stalk 0.7–1.3 mm long; ribs 12–18; dried seeds 0.21–0.42 × 0.12–0.22 mm.

Distribution. Loei Province at 580 m elevation; north-central Laos (Khammousan Province). There are two adjacent localities in a single stream in Phu Suan Sai National Park in Na Haeo District. The species distribution range is 0.01 km^2. The population is not declining.

Conservation status. Near Threatened (NT B1a+2a).

Specimens examined. NE Thailand, Loei Province: Tat Hueang waterfall, Phu Suan Sai (Na Haeo) natl. park 579 m alt., 17°33′57.5″ N, 100°59′28.2″ E, 8 Dec. 2009, fl. buds, fl. fr., *P. Werukamkul & L. Ampornpan TWA28, TWA29, TWA30, TWA31, TWA32*, 27 Dec. 2009, fr., *P. Werukamkul & L. Ampornpan TWA70*; Gaeng Wang Palat, Na Haeo dist., 581 m alt., 17°34′3.2″ N, 100°58′58″ E, 1 Jan. 2010, fl. fr., *P. Werukamkul & L. Ampornpan TWA91, TWA92, TWA93.*

We thank Patanajak Duang-uppa and Pipat Bunchim for their help on the collecting trips; Srinakharinwirot University for providing accommodation at Na Haeo; and the National Museum of Nature and Science (Japan) for allowing P. Werukamkul and L. Ampornpan to use the facilities for the present study. We are also indebted to D. E. Boufford for the linguistic corrections. This study was supported by a Thailand Research Grant for fiscal year 2010 (to P.W., L.A.) and a Grant-in-Aid for Scientific Research from the Japan Society for the Promotion of Science (to M.K.).

References

Cook, C. D. K. 1996. Aquatic Plant Book. 2nd rev. ed. SPB Academic Publishing, The Hague.

Cook, C. D. K. & R. Rutishauser. 2007. Podostemaceae. *In*: Kubitzki, K. (ed.), The Families and Genera of Vascular Plants. Vol. 9: 304–344. Springer, Berlin.

Cusset, C. 1992. Contribution à l'étude des Podostemaceae: 12. Les genres asiatiques. Bul. Mus. Natl. Hist Nat., Sect. B, Adansonia 14: 13–54.

Cusset, C. & G. Cusset. 1988. Etude sur les Podostemales: 9. Délimitations taxonomiques dans les Tristichaceae. Bul. Mus. Natl. Hist Nat., Sect. B, Adansonia 10: 149–177.

IUCN Standards and Petitions Subcommittee. 2011. Guidelines for Using the IUCN Red List Categories and Criteria. Version 9.0. Prepared by Standards and Petitions Subcommittee. Downloadable from http://www.iucnredlist.org/documents/RedListGuidelines.pdf.

Kato, M. 2004. Taxonomic studies of Podostemaceae of Thailand. 1. *Hydrobryum* and related genera with crustaceous roots (subfamily Podostemoideae). Acta Phytotax. Geobot. 55: 133–165.

Kato, M. 2006a. Taxonomic studies of Podostemaceae of Thailand. 2. Subfamily Tristichoideae and subfamily Podostemoideae with ribbon-like roots. Acta Phytotax. Geobot. 57: 1–54.

Kato, M. 2006b. Distribution and biogeography of Podostemaceae in Asia. Bull. Natl. Sci. Mus. Tokyo, Ser. B. 32: 19–27.

Kato, M. 2011. Taxonomic enumeration of Podostemaceae of Cambodia and Vietnam. Bull. Natl. Mus. Nat. Sci., Ser. B. 37: 1–8.

Kato, M. & N. Fukuoka. 2002. Two new species of *Diplobryum* (Podostemaceae, Podostemoideae) from Laos. Acta Phytotax. Geobot. 53: 115–120.

Kato, M. & S. Koi. 2009. Taxonomic studies of Podostemaceae of Thailand. 3. Six new and rediscovered species. Gard. Bull. Strait Settlem. 61: 55–72.

Kato, M., S. Koi & Y. Kita. 2004. A new foliose-rooted genus of Podostemaceae from Thailand with a note on root evolution. Acta Phytotax. Geobot. 55: 65–73.

Koi, S. & M. Kato. 2010. Developmental morphology of seedling and shoot and phylogenetic relationship of *Diplobryum koyamae* (Podostemaceae). Amer. J. Bot. 97: 373–387.

Koi, S. & M. Kato. 2012. Taxonomic study of Podostemaceae subfamily Podostemoideae of Laos with phylogenetic analyses of *Cladopus*, *Paracladopus* and *Polypleurum*. Kew Bull. 67(3): 331–365.

Koi, S., Y. Kita, Y. Hirayama, R. Rutishauser, K. A. Huber & M. Kato. 2012. Molecular phylogenetic analysis of Podostemaceae: Implications for taxonomy of major groups. Bot. J. Linn. Soc. 169: 461–492.

Sculthorpe, C. D. 1967. The Biology of Aquatic Vascular Plants. Edward Arnold, London (reprinted 1985 by Koeltz Scientific Books, Königstein).

Tanaka, N., S. Kobayashi, T. Ohi-Toma & J. Murata. 2006. New or noteworthy plant collections form Myanmar (1). *Hydrobryum japonicum*, *Balanophora subcupularis*, *Rhopalocnemis phalloides* and *Sonerila laeta*. J. Jap. Bot. 81: 324–331.

Warming, E. 1901. Podostemaceae. *In*: Schmidt, J. (ed.) Flora of Koh Chang: contributions to the knowledge of the vegetation in the Gulf of Siam. Bot. Tidsskr. 24: 241–327.

Willis, J. C. 1902. Studies in the morphology and ecology of the Podostemaceae of Ceylon and India. Ann. Roy. Bot. Gard. (Peradeniya) 1: 268–465, pl. IV–XXXVIII.

Received May 8, 2012; accepted July 25, 2012